Cooperation v/s Non-cooperation in R&D Competition with Spillovers

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Abstract

This paper seeks to analyse a case in which firms choose to divide their R&D expenditures into two components: competitive R&D and Joint-Venture R&D. The analysis is motivated by the fact that R&D outputs can have different degrees of non-excludability. It is therefore reasonable to expect that a firm will allocate a part of its funds to competitive R&D; this is the case in areas in which research is non-excludable to a smaller degree, and part of it to Joint-Venture R&D, in cases where R&D output is highly non-excludable. This issue is addressed in a three-stage model of a duopoly, in which joint-venture R&D and competitive R&D are chosen in the first and second stages while the quantity of the product is chosen in the third stage. The results confirm that allocation of expenditure to the joint-venture component increases as the spillover rate on the competitive component increases. Furthermore, if firms are able to coordinate their joint-venture R&D levels, there is greater incentive to increase this allocation. However, for these results to obtain, it is crucial that the two types of R&D are chosen sequentially; a simultaneous choice would lead to a corner solution in which only competitive R&D is chosen.

1. Introduction

In recent years, the analysis of cooperative and non-cooperative research and development (henceforth R&D) in the presence of spillovers has been an active area of research. Much of this literature has been based on the approach taken by d'Aspremont and Jacquemin (1988), who examine this issue in the framework of a two-stage model of a duopoly, in which cooperative or non-cooperative research levels are chosen in the first stage, while in the second stage firms engage in Cournot competition in the product market. Their model is characterized by the presence of a positive externality created by a firm's R&D activity; part of the information about a completed R&D project costlessly leaks to its rivals who are consequently able to benefit from the resulting cost reductions as well.

This externality has been referred to as an *output spillover* in subsequent literature, in contrast to an *input spillover* in Kamien et al. (1992), which leads to leakage of information at the research stage before the innovation takes place. (See, for example, Amir (2000), Martin (2002), and Hauenschild (2003), among others.) Kamien et al. also distinguish between the possibility of R&D coordination and information sharing. In the presence of information sharing, it is postulated that the spillover effect increases and a *research joint venture* is formed. In addition they analyse the case of differentiated products and Bertrand price competition in the product market. In Hauenschild (2002) the basic d'Aspremont and Jacquemin (1988) model and the Kamien et al. (1992) model, was extended to include the possibility of uncertain R&D outcomes.

In all of the above cases, it is implicitly assumed, that investment of resources in non-cooperative R&D precludes investment in cooperative R&D, or in research joint ventures, and vice versa. In the real world, it is possible to conceive of situations in which firms allocate part of their R&D expenditure to cooperative or joint research, while part of R&D is conducted non-cooperatively. To motivate why this may be the case, we focus on a particular feature of R&D output, which is also typical of public goods. This is the *partial* non-excludability of this output. The extent of non-excludability is determined by legal measures available to make this output appropriable as well as the nature of this output. Here, we wish to emphasize that certain types of research yield output that may be appropriable to a greater degree than other types of research. The R&D by a firm typically involves research that yields both types of output – i.e., part of which is not appropriable in the sense that it involves a large spillover, and a part which can be kept secret, or protected by patents. It is therefore reasonable to expect that a firm will allocate some of its funds to non-cooperative R&D, in areas of research in which there is high appropriability, while in other areas it may have incentive to invest in a research joint venture.

The purpose of this paper is to analyse a case in which firms choose to divide their R&D expenditure into two components: competitive R&D and joint-venture R&D. This issue is addressed in the framework of a *three stage* game of duopoly competition. Two cases are considered. In the first stage, the two firms form a research joint venture and can decide to cooperate by choosing joint-venture R&D levels to maximize joint profits, or alternatively act like Cournot competitors, although information resulting from R&D in this stage is fully shared in either case. The two cases are similar to what Kamien et al. refer to as "research joint venture cartelization" and "research joint venture competition" respectively. Competitive R&D is chosen in the second stage, in which firms take the joint-venture R&D levels in the first stage as given. In the third stage the quantities of the homogeneous product produced by the two firms are chosen, while R&D levels chosen in the previous stages are taken as given. There is Cournot competition in the last two stages. Competitive R&D is characterized by a fixed spillover less than one, while in the case of joint venture R&D; the spillover is set equal to one.

Results of this analysis indicate that lower appropriability of the competitive component of R&D motivates firms to allocate a larger component of their expenditure to the joint-venture component. This motivation is enhanced if the firms are able to coordinate first-stage R&D in order to maximize joint profits. However the crucial element underlying these results is the three stage nature of the game. Simultaneous choice of joint-venture and competitive R&D would, of course, result in a corner solution in which firms only invest in competitive R&D.

In what follows, Section 2 describes and solves the model, which is a simple extension of the d'Aspremont and Jacquemin (1988) framework. In this section we also use some numerical simulations to examine parameter combinations in which joint-venture R&D exceeds competitive R&D and vice versa. Section 3 summarizes the results and concludes.

2. The Model

There are two firms in the industry, characterized by the inverse demand function $D^{-1} = a - bQ$, where $Q = q_1 + q_2$ is the total quantity produced in this industry, q_1 and q_2 are the quantities produced by firms 1 and 2 respectively, and a and b are positive constants. The cost function of firm *i*, *i*=1, 2, $i \neq j$ is represented by

$$C_i(q_i, x_i^c, x_i^J, x_j^c, x_j^J) = [A - x_i^c - \beta x_j^c - x_i^J - x_j^J]q_i, \tag{1}$$

Where, x_i^c and x_i^J are the competitive and joint-venture components of firm *i*'s R&D expenditure. The joint-venture R&D levels are chosen prior to the competitive R&D levels, which in turn are decided before quantities for the product market are chosen. Also, $x_i^c + \beta x_j^c + x_i^J + x_j^J \leq A$, $Q \leq a/b$, $0 < A < a$, and $0 < \beta < 1$. The notation used here is similar to the d'Aspremont and Jacquemin (1988) framework; β is the cost reduction experienced by a firm due to a unit of the rival's competitive R&D expenditure. For a firm's joint-venture expenditure, the spillover is set equal to 1. The cost of R&D is assumed to be quadratic, of the form $\frac{1}{2}\gamma(x_i^c)^2$ and $\frac{1}{2}\gamma(x_i^J)^2$, for the competitive and joint-venture components respectively. The parameter γ is assumed to be positive.

In the product market, firms act as Cournot competitors and maximize individual profits conditional on the first and second stage R&D levels. Firm i's profit in the third stage is then given by

$$\pi_i = [a - bQ]q_i - [A - x_i^c - \beta x_j^c - x_i^J - x_j^J]q_i - \frac{\gamma(x_i^c)^2}{2} - \frac{\gamma(x_i^J)^2}{2}. \tag{2}$$

Standard derivations imply the following equilibrium quantities:

$$q_i = \frac{1}{3b}[a - A + (2-\beta)x_i^c + (2\beta - 1)x_j^c + x_i^J + x_j^J], \quad i = 1, 2;\ i \neq j. \tag{3}$$

Furthermore, the total quantity produced in the market is given by

$$Q = q_i + q_j = \frac{2}{3b}(a - A) + \frac{(1+\beta)}{3b}(x_i^c + x_j^c) + \frac{2}{3b}(x_i^J + x_j^J) \tag{4}$$

In the second stage of the game, firms choose the level of competitive R&D, by maximizing second stage profits, which can be written as:

$$\pi_i^* = \frac{1}{9b}[a - A + (2-\beta)x_i^c + (2\beta - 1)x_j^c + x_i^J + x_j^J]^2 - \frac{\gamma(x_i^c)^2}{2} - \frac{\gamma(x_i^J)^2}{2} \tag{5}$$

Note that if we set joint-venture R&D levels equal to zero, the second stage profits here correspond to the first stage profits of the two-stage d'Aspremont and Jacquemin model.

The symmetric solution in this stage yields x_1^c and x_2^c as functions of joint-venture R&D levels in the first stage:

$$x_1^c = x_2^c = \frac{2(2-\beta)}{9b\gamma - 2(1+\beta)(2-\beta)}[x_1^J + x_2^J + a - A]. \tag{6}$$

Now consider the case in which the firms choose joint-venture R&D levels to maximize individual profits. In this case, although the information resulting from R&D efforts is shared, firms do not cooperate in the sense of coordinating R&D levels. The solution for first-stage joint-venture R&D levels in this case is given by:

$$x_1^J = x_2^J = \frac{a-A}{\dfrac{[9b\gamma - 2(1+\beta)(2-\beta)]^2}{18b\gamma - (4-2\beta)^2} - 2} \tag{7}$$

In the second three-stage game, the firms also coordinate their joint-venture R&D levels in order to maximize joint profits. Again, we derive the symmetric solution:

$$x_1^J = x_2^J = \frac{a-A}{\dfrac{[9b\gamma - 2(1+\beta)(2-\beta)]^2}{36b\gamma - 2(4-2\beta)^2} - 2} \tag{8}$$

Comparing the coordinated and uncoordinated joint-venture R&D levels, it is clear that joint R&D is higher in the case where R&D in the first stage is chosen to maximize joint profits. As competitive R&D is increasing in joint-venture R&D, this implies that competitive R&D levels will also be higher in the latter case. Consequently, output levels will also be higher. These results are analogous to those obtained in two-stage models of R&D competition.

It is difficult to analyse under what conditions joint-venture R&D is larger than competitive R&D chosen in the second stage. However, numerical simulations based on parameter combinations consistent with the second order conditions clearly illustrate what would be expected on the basis of intuition. First, let us analyse the case in which we have uncoordinated joint-venture R&D in the first stage. Figure 1 presents competitive and joint-venture R&D levels as a function of β, the spillover on competitive R&D. Joint-venture R&D levels are represented by the solid line, while competitive R&D levels are represented by the dashed line. As indicated by this figure, the competitive R&D levels typically decrease as β increases, while joint-venture R&D levels increase as β increases[1]. For large values of β, joint-venture R&D levels exceed competitive R&D levels[2]. Intuitively, as the degree of excludability of the competitive component decreases, the firm has greater incentive to engage in joint-venture R&D.

Now consider the case in which firms coordinate their first-stage joint-venture R&D levels as a cartel. Figure 2 illustrates the results for this case, which are similar to case in which there is no coordination. However, in this case, joint-venture R&D exceeds competitive for much smaller values of the spillover parameter β[3]. Again, the intuition is straightforward: if the firms are able to form a cartel, there is greater incentive to internalize the externality created, in the interest of higher joint profits.

[1] This can be shown to be true for parameter values consistent with the second order conditions.

[2] In the case where there is no coordination of first stage R&D, this typically happens for values of β greater than 0.9.

[3] In this case the critical value of β is typically around 0.15.

It is important to emphasize here that these results are possible only if the game is played in three stages. It can be easily shown that in the two-stage variant of this model, in which competitive and joint-venture R&D levels are chosen simultaneously in the first stage, there is a prisoner's dilemma: firms only invest in competitive R&D.

3. Concluding Remarks

This paper analyses the case in which firms choose to divide their R&D expenditures into two components, depending on the degree of excludability of different types of R&D activity. This issue is addressed in a simple extension of the d'Aspremont and Jacquemin (1998) model. Specifically, we construct a three-stage model of R&D competition, in which firms choose joint-venture R&D, competitive R&D, and product output levels respectively in the first second and third stage of the game. As expected, the results confirm that allocation of expenditure to the joint-venture component increases as the spillover rate on the competitive component increases. Furthermore, if firms are able to coordinate their joint-venture R&D levels, there is greater incentive to increase this allocation. However, it is essential that the choice of different types of R&D levels is played as a sequential game.

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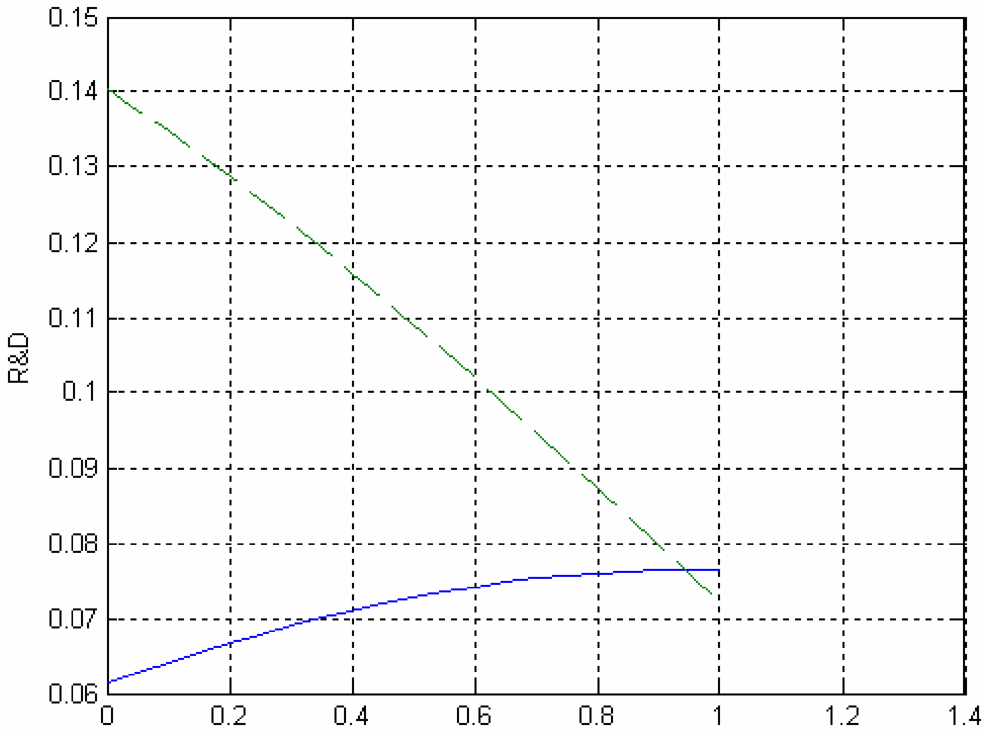

Spillover rate $(\beta)\rightarrow$

Figure 1: Competitive and Joint-Venture R&D as a function of β. (Cournot Competition in all three stages)

------- Competitive R&D; ______Joint-Venture R&D.

Other parameters: a=2; A=1; b=2; $\gamma = 2$.

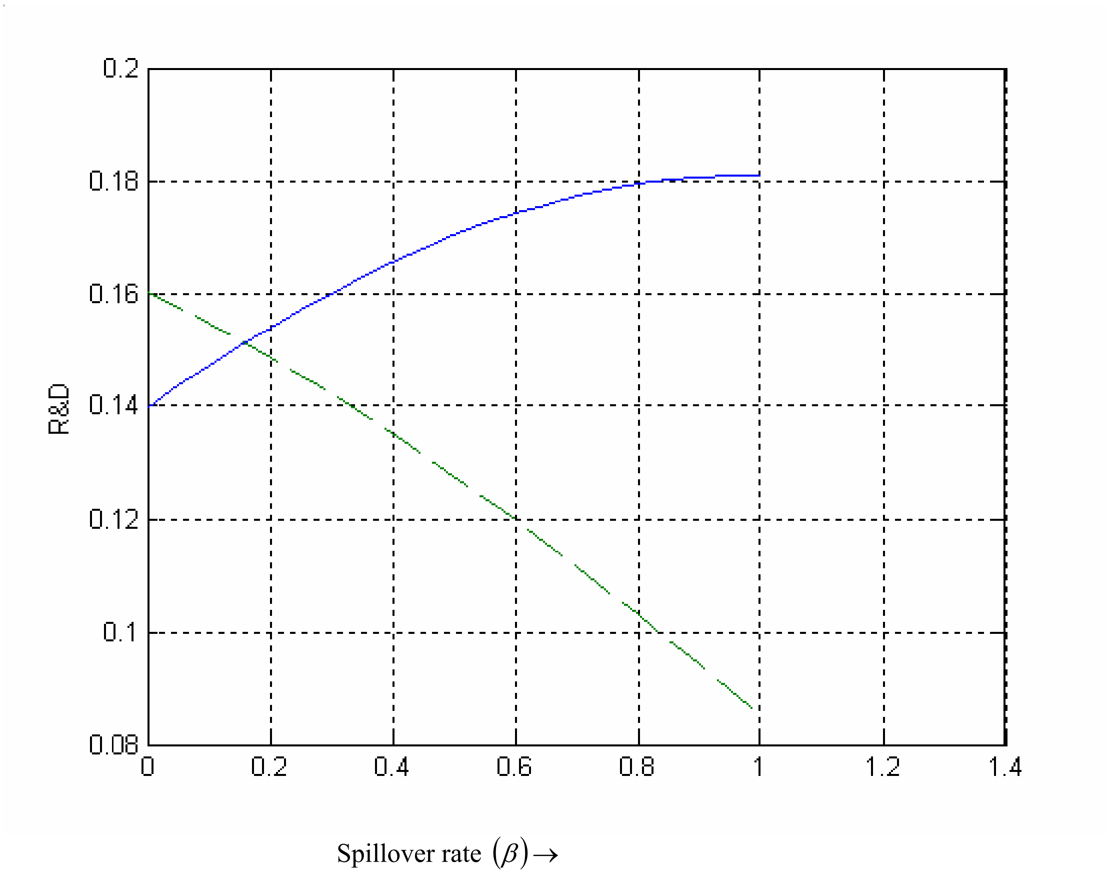

Figure 2: Competitive and Joint-Venture R&D as a function of β . (Cooperation in the first stage)

------- Competitive R&D; ______Joint-Venture R&D.

Other parameters: a=2; A=1; b=2; $\gamma = 2$.

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